Comment on "Requirement of optical coherence for continuous–variable quantum teleportation" by Terry Rudolph and Barry C. Sanders

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The argument of Rudolph and Sanders, while technically correct, raises conceptual problems. In particular, if carried to its logical conclusion, it would disallow the use in our theories of any time t with implied resolution beyond that of direct human experience.

In a recent paper [1], Rudolph and Sanders have argued that, contrary to Ref. [2], continuous–variable quantum teleportation has not been and, in fact, cannot be, achieved using a laser as a source of coherent radiation. They base their argument on the fact that a laser is *not* a source of coherent radiation, in the sense that the output of a laser is not a coherent state, but a mixture of coherent states over all possible phases. Although the formal analysis of Rudolph and Sanders is indisputably correct, there are deep conceptual issues raised by this analysis that they seem not to have considered.

Having established, following Mølmer [3], the lack of absolute phase of a laser beam, Rudolph and Sanders say that they are not asserting that the production of coherent states of light is impossible, and that "basic quantum electrodynamics shows that a classical oscillating current can produce coherent states." At first sight this seems unassailable, but let us examine it more closely.

First, how would one obtain a current oscillating at optical frequencies? The natural oscillators at optical frequencies are the electrons in atoms and molecules. But how can one create coherent excitations in such oscillators if one cannot start with coherent light? One answer would be to "strike" the atom (with a free electron, for example), to set it "ringing". Even assuming that the dynamics of the collision can be fully determined, to produce a coherent oscillation, the time of the collision would have to be known to an accuracy less than an optical cycle, of order 10^{-15}s. Otherwise one would have to average over all possible phases and one would be left with exactly the same problem as with the laser.

Let us say for arguments sake that it is possible to know the time of collision to an accuracy of 10^{-15}s. The question is, with respect to what? What clock ticks 10^{15} times per second? If we ignore that problem and allow Alice and Bob such clocks, ticking in phase, then surely this solves the problem? Well not really, because how do we know that the clock really has a definite phase? How do we know that, relative to the absolute time of the universe, Alice's clock does not have a random phase? Certainly Alice cannot simply look at her clock and verify that it does not have a random phase, because she cannot perceive anything in 10^{-15}s.

The point is that the whole idea of an absolute time standard for the universe is highly questionable, even ignoring any issues to do with relativity. As conscious beings we feel that we experience time directly, but experiments show that the limit of our time resolution is in the range of tens or even hundreds of milliseconds [4]. On this basis, *it is impossible to establish the absolute phase of any oscillator of frequency greater than a few tens of Hertz.* At higher frequencies we can only talk about the phase of one oscillator relative to another oscillator. This conclusion is not altered by oscillations obtained by frequency 2^n-upling, because the timing of the zeros of the highest harmonic can be no more accurately defined than that of the fundamental.

It follows then that, if we accept the arguments of Rudolph and Sanders, we must conclude that it is impossible to teleport the state of a high-frequency oscillator by any means. Indeed, we should conclude that the state of any high frequency oscillator is always mixed (with all phases equally weighted) so there is probably little point in trying to teleport it.

While this stance is a logically consistent one, it is far more useful to acknowledge that there is no absolute time standard. All we can ever do, for experiments involving time resolution beyond direct human experience, is to use an agreed time standard. In this context, a laser field "ticking" at 10^{15} Hz is as good a "clock" as anything. *There are no better clocks, even in principle.*

To conclude, treating a laser "clock" as if it had a fixed phase relative to some absolute standard (that is, ascribing to it a coherent state) may be a "convenient fiction" [3]. It may even be committing the "partition ensemble fallacy" [5]. However, the alternative, if carried to its logical conclusion, would be never to write down a time t or a phase ϕ in our theories if its implied resolution would be beyond that of direct human experience. To scientists and engineers, this would be unacceptable pedantry.

[1] T. Rudolph and B.C. Sanders, quant-ph/0103147
[2] A. Fursawa *et al.*, Science **282**, 706 (1998).
[3] K. Mølmer, Phys. Rev. A **55**, 3195 (1996).
[4] R. Penrose, *The Emperor's New Mind* (Vintage, London, 1990)
[5] P. Kok and S.L. Braunstein, Phys. Rev. A **61**, 042304 (2000).